

**A USERS GUIDE FOR THE ANL VERSION OF  
THE PARET CODE,  
PARET/ANL (2001 Rev.)**

by

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**ANL/RERTR/TM-16**  
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## **ABSTRACT**

The original PARET code has been adapted by the Reduced Enrichment Research and Test Reactor (RERTR) Program to provide transient and thermal-hydraulics analysis for research and test reactors with both plate and pin type fuel assemblies. The PARET/ANL version of the code has been subjected to extensive comparisons with the SPERT I and SPERT II (light water and heavy water) experiments. These comparisons were quite favorable for a wide range of transients up to and including melting of the clad. The code has also provided good agreement with pulsed TRIGA transients in pin geometry. The revisions for this version of the code are described. These include new and more appropriate heat transfer, DNB and flow instability correlations, improved edits, reactor trips, control insertion model, decay heat power model, a time-dependent pump flow model, and a loss-of-flow model with flow reversal. The code now includes a restart option and generates a summary file for further processing of the results. Auxiliary support codes are available for generating properties libraries for both light and heavy water and for post processing of the summary file data. While the PARET/ANL code does not include a plotting package, the processed summary data is cast in a format acceptable to most plotting applications. The current input requirements and descriptions are provided. The code accepts input and generates output in SI units on option. While it is useful to have the original PARET code manual available for reference, this Users Guide should be sufficient for most purposes. The PARET/ANL code is FORTRAN 77 compatible and runs on both PCs (Windows and Linux) and UNIX workstations.



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## 1. INTRODUCTION

The PARET/ANL Code is intended primarily for the analysis of plate type research and test reactors. This version of PARET has been subjected to extensive comparisons with the SPERT I and SPERT II experiments (William L. Woodruff, "The PARET Code and the Analysis of the SPERT I Transients," ANL/RERTR/TM-4 (1982), W. L. Woodruff, "A Kinetics and Thermal-hydraulics Capability for the Analysis of Research Reactors," Nucl. Technol., 64, 196 (1984), and W. L. Woodruff, "Additional Capabilities and Benchmarking with the SPERT Transients for Heavy Water Applications of the PARET Code," Proc. Int. Mtg. On RERTR, Berlin, Germany (1989)). These comparisons were quite favorable for a wide range of transients up to and including melting of the clad. Favorable comparisons have also been made for TRIGA reactor pulses in pin geometry. The PARET/ANL code has been used by the RERTR Program for the safety evaluation of many of the candidate reactors for reduced enrichment.

The following information is intended to supplement and in some cases make corrections to the original PARET Code Manual (C. F. Obenchain, "PARET -- A Program for the Analysis of Reactor Transients," IDO-17282 (1969)). The reader/user is assumed to have at hand this document, although it is not an absolute necessity. The terminology and notation when not defined in the text are consistent with that used in the PARET Manual.

The initial FORTRAN and assembly language version of the code was submitted to the National Energy Software Center (NESC) and last revised in 1973 (Abstract 555). The current ANL version of the code is a modification of this edition. A processing-editing code for the summary file now generated by PARET is described. An updated coolant properties library can be generated with a FORTRAN auxiliary code, and an all FORTRAN version of the PARET Code is available for ease of conversion to other platforms. The current code is available for either UNIX workstations or PCs (Windows and Linux).

The PARET/ANL modifications which require changes or corrections to the input described in the PARET Manual will be covered by card type. Other changes and additions are described. The revised input section (Section 6) contains the most recent description of the PARET/ANL code input.

## 2. INPUT CHANGES

### 1000 Series Cards

The PARET code will now accept data input in the International System (SI) units on user option. If the number of channels NCHN is input as a negative integer (first parameter input), the code assumes that all the input to follow is in SI units (m, kg, J, W, Pa, K). The code and properties library still use units of ft, lb., Btu, psia and °F by conversion of the SI units. The conversion factors used in the code are listed in the Appendix. With the SI units option, the output is also in SI units with the exception of temperatures which are given in °C. The 200N card coefficients for the conductivity ( $\alpha_i$ ) and heat capacity ( $\beta_i$ ) of fuel and clad are assumed to be input in units of K, however, units in °C may be used if  $\alpha_5$  and/or  $\beta_5$  are set to -273.15 in the input. The coefficients ( $\gamma_i$ ) for Doppler feedback may be treated in the same way. Only two input parameters require further discussion with the SI option. These are the conversion factors  $P_f$  (entry 15) and  $P_c$  (described in 1111 card). Since the conversion from MW to Btu/hr is not required with SI units, the parameter  $P_f$  is just the volume of fuel [ $m^3$ ] and  $P_c$  is the flow area [ $m^2$ ].

It should also be pointed out that this NESC FORTRAN version of the PARET code does not have a minimum allowable time step, DTMIN, implemented. Thus, the 49th (last) entry in the 1000 series cards must be omitted.

### 1111 Card

The description of the 1111 card as received from NESC, Attachment 1, does not fully explain all of the data which may be entered on this card. The constant,  $P_c$ , is a conversion factor

$$P_c = \frac{3.41376 \times 10^6}{\text{FlowArea}[\text{ft}^2]} \quad [\text{BTU/hr ft}^2/\text{MW}]$$

and is edited under "GENERAL INFORMATION" as "INTEGRATION CONST =". On option channel dependent factors may be entered (default value 1.0) following  $P_c$ . These factors are edited under "INDIVIDUAL CHANNEL INFORMATION" as "FLUX WEIGHTING FACTOR =" by channel. The intended purpose of these factors is not clear. They are apparently used only to adjust the edited values of power and energy release by channel.

### 1112 - 1114 Cards

Three new cards have now been added to the input requirements and must be included after the 1111 card.

The PARET code now supports a selection of heat transfer, flow instability, and DNB correlation's and includes a tabulation of decay heat power based on the ANS curve

for fission product decay heat. The code also provides a simulation of control rod reactivity insertion with rate and delay time settings and trip points for low flow and overpower. The required input for the 1112, 1113 and 1114 cards follow:

#### 1112 Card

1112, IONEP, ITWOP, IMODE, ICHF, IHT, QAVE, ETA, CP

- |       |   |   |
|-------|---|---|
| IONEP | - | Single Phase Correlation Flag<br>0 - original Dittus-Boelter<br>1 - Seider-Tate<br>2 - Petrukov-Popov (must have IHT=0)   |
| ITWOP | - | Two Phase Correlation Flag<br>0 - original Jens-Lottes<br>1 - McAdams<br>2 - Bergles-Rohsenow   |
| IMODE | - | Transient Two Phase Scheme<br>0 - original model<br>1 - transition model  |
| ICHF  | - | DNB and Flow Instability Correlation's<br>0 - original DNB<br>1 - Bernath DNB<br>2 - Mirshak DNB<br>3 - Forgan FIR* (plane geometry only)<br>4 - CEA FIR* (plane geometry only)<br>5 - Lund DNB (pin geometry only)<br>6 - Lund DNB with bowed pin included |
| IHT   | - | Single Phase Heat Transfer Subroutine Use<br>0 - original<br>1 - revised, without entrance effects for h<br>2 - revised, with entrance effects for h included   |
| QAVE  | - | Average (core) heat flux used with ICHF = 3 & 4 [BTU/hr. ft <sup>2</sup> ]  |
| ETA   | - | Eta value for ICHF - 3 (default 25)   |
| CP    | - | Specific heat used with ICHF - 3 & 4 [BTU/lb. °F] (default 1.0)   |

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\*See following pages

The flow instability ratios (ICHF = 3 and 4) are defined as follows:

$$\mathbf{FIR} = \mathbf{q_{FI}} / \bar{\mathbf{q}}$$

where

$$\mathbf{q_{FI}} = \mathbf{R} \frac{\rho \mathbf{C_p}}{4} \frac{\mathbf{D_H}}{\mathbf{L_H}} \mathbf{v} (\mathbf{T_{sat}} - \mathbf{T_{in}})$$

and

$$\bar{\mathbf{q}} = \begin{array}{l} \text{Average heat flux at normal steady-state power (QAVE)} \\ \text{peaking factors if the hot channel modeled.} \end{array}$$

with

$$\underline{\mathbf{ICHF} = 3}$$

$$\mathbf{R} = \frac{1}{1 + \eta \frac{\mathbf{D_H}}{\mathbf{L_H}}}$$

$$\underline{\mathbf{ICHF} = 4}$$

$$\mathbf{R} = \frac{1}{1 + 3.15(\mathbf{MFR})^{0.29} \frac{\mathbf{De}}{\mathbf{L_H}}}$$

$\rho$	=	Density of the coolant [g/cm <sup>3</sup> ]
$\mathbf{C_p}$	=	Specific heat of coolant (CP) [J/g °C]
$\mathbf{D_H}$	=	Equivalent heated diameter [cm]
$\mathbf{L_H}$	=	Heated length [cm]
$\mathbf{v}$	=	Coolant flow-velocity [cm/s]
$\mathbf{T_{sat}}$	=	Saturation temperature [°C]
$\mathbf{T_{in}}$	=	Inlet temperature [°C]

$$\eta = \text{Bubble detachment parameter (ETA)} \left[ \frac{\text{cm}^3 \text{ } ^\circ\text{C}}{\text{J}} \right]$$

$$\text{De} = \text{Equivalent wetted diameter [cm]}$$

$$\text{MFR} = \text{Mass Flow Rate [g/cm}^2\text{s]}$$

This form of the average heat flux at the onset of flow instability,  $q_{FI}$ , assumes that  $\eta$  is a minimum at the channel exit, and that the heat flux at the channel exit is representative of this average heat flux.

A transition model to fully developed two phase heat transfer (IMODE=1), as suggested by Bergles and Rohsenow, has been implemented in PARET as an option to the original model. This two phase transition scheme at time step  $m+1$  may be expressed as

$$(q'')^{m+1} = (q''_{1\phi})^{m+1} \left\{ 1 + \left[ \frac{(q''_{2\phi})^{m+1}}{(q''_{1\phi})^{m+1}} \left( 1 - \frac{(q''_i)^{m+1}}{(q''_{2\phi})^{m+1}} \right) \right]^2 \right\}^{1/2}$$

where

$$q''_{1\phi} \text{ is the single phase heat flux } \sim h_{1\phi}$$

$$q''_i \text{ is the two phase value } \sim (T_{wi} - T_{sat})$$

and

$$q''_{2\phi} \text{ is the two phase value } \sim (T_w - T_{sat})$$

with the clad wall temperature at the onset of nucleate boiling (ONB) given by

$$T_{wi} = (q''_{ONB} / 15.6 p^{1.156})^{\frac{p^{0.0234}}{2.30}} + T_{sat}, \text{ the Bergles-Rohsenow correlation (B-R).}$$

The two phase correlation for  $q''_i$  and  $q''_{2\phi}$  may be chosen from the original Jens-Lottes (J-L), the McAdams, or the B-R correlation's on option. For comparison the original scheme (IMODE=0) is

$$(q'')^{m+1} = (q'')^m \left\{ 1 + \frac{4 [T_w^m + 1 - (T_w^x)^m]}{(T_w^x)^m - T_{sat}} \right\}$$

where  $(T_w^x)^m \sim (q'')^m$  for  $T_w^{m+1} > (T_w^x)^m$  with again the same option for  $(q'')^m$  of J-L, McAdams, or B-R.

### 1113 Card

1113, RDRATE, TDLAY, POWTP, FLOTP, OPT, POW0

RDRATE - Either rate for control rod movement [ft/sec or m/sec] or a -1.0 for tabulated data.

TDLAY - Delay time before rod starts in after trip [sec] (default 36000 sec)

POWTP - Overpower trip point [MW] (default 10000 MW)

FLOTP - Low flow trip point [%] (default 0.0%)

OPT - Previous operation time of reactor - Used in decay heat level after scram [da] (default 24.0 da)

POW0 - Previous operating power of the reactor - Used in decay heat power after scram [MW] (default - initial power input for startup of transient)

### 1114 Card

1114, HNCTOP

HNCTOP - Height above reactor for natural convection effects

### 5000 Series Cards

The PARET code has also been modified to include a separate channel dependent coolant temperature coefficient and axial weighting distribution. These data are input as additional entries on the 5k00 and 5kXX cards (see Ch.IV, sect. 2.6 and 2.63 of PARET Manual).

5k00 - The coolant temperature coefficient for channel k,  $\alpha_k$ , is the 11th entry. Entering 0.0 gives the original coolant void coefficient only capability.

51XX - The coolant temperature coefficient weighing factor,  $WF_{j,k}$ , for channel k and axial node  $j=XX-1$  is the 6th entry.

The reactivity feedback from changes in the coolant temperature at the time step m is given by

$$\delta\rho^m_{TC} = \frac{1}{V_{Mod}} \sum_{k=1}^{NCHN} X_{k2} \alpha_k \sum_{j=1}^{NZ} (V_{Mod})_{j,k} WF_{j,k} (T^m_{j,k} - T^o_{j,k})_B$$

in units of dollars. The units of the products  $\alpha_k \times WF_{j,k}$  must be in units of \$/°F. A uniform distribution for the temperature coefficient can be specified by setting all  $WF_{j,k} = 1.0$ , however, this choice may dictate a re-normalization of the coefficients. For example, assume that each region of the reactor has been uniformly perturbed by a one degree change in temperature, and coefficient for each channel,  $\alpha_j$ , have been obtained such that  $\sum_k \alpha_k = \alpha_T$ .

Then with  $WF_{j,k} = 1.0$ ,

$$\delta\rho^m_{TC} = \frac{1}{V_{Mod}} \sum_{k=1}^{NCHN} X_{k2} \alpha_k \sum_{j=1}^{NZ} (V_{Mod})_{j,k} (T^m_{j,k} - T^o_{j,k})_B$$

and the  $\alpha_k$  data must be normalized as

$$\alpha'_k = \frac{\alpha_k}{\frac{1}{\alpha_T V_{Mod}} \sum_{n=1}^{NCHN} X_{n2} \alpha_n \sum_{i=1}^{NZ} (V_{Mod})_{i,n}}$$

A convenient normalization for the weighting factors is

$$WF'_{j,k} = \frac{WF_{j,k}}{\frac{1}{V_{Mod}} \sum_{i=1}^{NZ} (V_{Mod})_{i,k} WF_{i,k}}$$

then

$$\frac{1}{V_{Mod}} \sum_{k=1}^{NCHN} X_{k2} \alpha_k \sum_{j=1}^{NZ} (V_{Mod})_{j,k} WF'_{j,k} = \alpha_T$$

reduces to

$$\sum_{k=1}^{NCHN} X_{k2} \alpha'_k = \alpha_T \quad \text{and} \quad \alpha'_k = \alpha_k / X_{k2}.$$

With this choice of normalization, the coefficients specified by channel must be in units of \$/ °F, per unit volume fraction of the channel.

It may be necessary to apply this same sort of normalization to the density/void coefficients and weighting factors. Contrary to statements and equations in the PARET Manual the units of the composite density/void coefficient and weighting factors must be input in units of \$/% void.

Similar arguments may be applied to the choice of coefficients for the Doppler feedback. In this case the appropriate units are \$/°R to give the reactivity feedback in dollars. If the coefficients are given in units of \$/ °F, the temperature in the feedback equation (°R) can be converted to °F by setting the input parameter,  $\gamma_4$ , to the value -459.58.

The description of the natural convection heat transfer correlation in Appendix C of the PARET Manual requires some Corrections and clarification. The term  $D_e$  in Eqs. (C-1) and (C-3) would appear to be the equivalent diameter for the channel, but the code actually uses  $D_e^{0.6} L_F^{0.4}$ , where  $L_F$  is the fueled length. Also the characteristic length  $D$  in Eq. (C-6) and (C-9) should be replaced with the product  $Gr \times Pr$ . In preliminary studies with no sub-cooled boiling it was apparent that this heat transfer correlation for natural convection (Reynolds number,  $Re < 2000$ ) was inadequate, and that the heat transfer coefficient was too low. Thus, the single phase heat transfer coefficient proposed by Rosenthal and Miller (“An Experimental Study of Transient Boiling”, ORNL-2294, 1957) as

$$h = \sqrt{\frac{k\rho C_p}{T}}$$

where

- $h$  = the heat transfer coefficient at the clad-coolant interface
- $k$  = the thermal conductivity of the coolant
- $\rho$  = the density of the coolant
- $C_p$  = the specific heat of the coolant
- and  $T$  = the period of the power rise

This expression is based on the analysis of transient experiments in which the power in an electrically heated ribbon was increased exponentially as  $e^{t/T}$  with the time,  $t$ , and should be valid for  $t > T$ . This coefficient may now be used with both natural and forced convection if the value is larger than the original heat transfer coefficient for  $Re < 2000$ , and if this coefficient is larger than that computed for the chosen forced convection correlation with  $Re > 2000$ . The use of this method requires the selection of an appropriate period. In the current version of PARET,  $T$  is chosen as the minimum  $T_m$



such that  $|T_m - T_{m-1}|/T_{m-1}$  is less than 0.01, where  $T_m$  is the instantaneous period at the time step  $m$ . This has proven to be a reasonable criterion under most conditions.

### 3. OTHER MODIFICATIONS TO THE PARET CODE

Other modifications to the PARET/ANL code include the following:

- (1) The major edits obtained at specified intervals have been modified to include an edit of the liquid quality (X).
- (2) The edits of the current date and running time were made operational on the present operating system.
- (3) A computation and edit for the bubble detachment parameter,  $\eta$ , has been added. The criteria for  $\eta$  at the  $i^{\text{th}}$  axial node is defined by

$$\eta_i = \frac{v_i (T_{\text{sat}} - T_B)_i}{q_i} \left[ \frac{\text{cm}^3}{\text{Ws}} \frac{^\circ\text{K}}{\text{Ws}} \right]$$

where

$v_i$  = Coolant velocity at node  $i$

$(T_{\text{sat}} - T_B)_i$  = Sub-cooling of coolant at node  $i$

$q_i$  = Surface heat flux at node  $i$

The minimum value of  $\eta$  is edited at each time step.

- (4) The code was modified to detect bulk boiling and to use the proper coolant density and friction factor for this regime. In this connection the boiling flag IBOIL is assigned the value 4 when bulk boiling occurs, and major edits show the moderator regime as 'BULK BOILING' for the appropriate coolant nodes.
- (5) The minor edits (at each time step) now include edits of the min. burnout ratio, min.  $\eta$ , max. temperatures for the fuel, clad and coolant, and the boiling flag value (worst case) as 'BOIL = N', where  $N = 0$  for no boiling,  $N = 1$  for nucleate boiling,  $N = 2$  for transition boiling,  $N = 3$  for film boiling,  $N = 4$  for bulk boiling, and  $N = -1$  for pure vapor. The edit also now shows the time step number along with the transient time.
- (6) The code now includes a modification in the friction factor used for laminar flow with  $Re < 2000$ :

$$\text{Plates} \quad f = 96/\text{Re} (\mu_w / \mu_b)^{0.14}$$

$$\text{Pins} \quad f = 64/\text{Re} (\mu_w / \mu_b)^{0.14}$$

where the subscripts w and b refer to coolant properties evaluated at the bulk and clad wall temperatures, respectively.

- (7) The maximum number of entries on 14000 cards is now 10.
- (8) Input data for Tables 16, 17 and 18 now allow control of frequency of major and minor printout, a description of pump mass velocity variation with time and a description of control worth versus position or time for control reactivity insertion.

A restart capability has been added to the PARET/ANL code, where a restart file is written to alternate units at specified intervals. The transient time, time step selection and print frequency selection may be changed at restart. A summary file is also now written by the current code. This file is described in the next section. The summary file records are written at the same frequency as the minor edits, and the minor edits include a summary file record number along with the time step number.

#### 4. POWER, REACTIVITY, TEMPERATURE, ETC. VS. TIME HISTORIES AND THE POSTPROS CODE

The PARET/ANL code writes a binary SUMMARY file to facilitate post-processing of the large amount of data that is often generated. This file contains a record for each summary step with the following format:

TIME, POWER, REAC, (AMFR(I), I=1, NCHN), (BRM (1), I=1, NCHN),  
(TCOOL (I), I=1, NCHN), (TCLAD(I),I=1,NCHN),  
(TCNTR(I),I=1,NCHN),(TCOUT(I),I=1,NCHN)

where	TIME	=	Time at each step, sec
	POWER	=	Power at each step, MW
	REAC	=	Net reactivity at each step, \$ and for each of the NCHN channels:
	AMFR	=	Mass flow rate at each step, lb <sub>m</sub> /hr ft <sup>2</sup>
	BRM	=	Min. critical heat flux ratio
	TCOOL	=	Max. coolant temperature, °C or °F
	TCLAD	=	Max. clad surface temperature, °C or °F

TCNTR	=	Max. fuel center line temperature, °C or °F
TCOUT	=	Coolant outlet temperature, °C or °F

An edit of this file provides a summary of the PARET/ANL results. A processing-editing routine has been written which will provide an edit of this file for selected records (in SI units) and process selected data for subsequent plotting. This routine (POSTPROS) also produces a card image file of power vs. time data in the format of the Table 9 (9000 cards) data for use in subsequent power driven transient analysis problems. The POSTPROS code runs interactively with prompts for user input data and optional online help.

The input for POSTPROS consists of the following input data:

- 1) NPTS - No. of points (summary steps) to be processed. If NPTS 0, conversion to SI units will be done (no conversion - defaults). NPTS should not exceed the number of time steps on the SUMMARY file.
- (2) NSKPS - No. of data in pairs for skipping data ( see NSKPF and NSKPP)
- (3) NCHN - No. of channels in PARET problem.
- (4) NPOW - 0 No processing, 2 process Power data
- (5) NREA - 0 No processing, 1 process Reactivity data
- (6) NMFR - 0 no processing, 1 process Mass Flow Rate data
- (7) NBRM - 0 No processing, 1 process Min. Critical Heat Flux data
- (8) NTCO - 0 No processing, 1 process Coolant Temperature data
- (9) NTCL - 0 No processing, 1 process Clad Temperature data
- (10) NTFL - 0 No processing, 1 process Fuel Temperature data
- (11) NTCOT - 0 No processing, 1 process Coolant Outlet Temperature data
- (12) NEDIT - 0 No edit, 1 print selected data
- (13) NPLOT - 0 No plot file(s) or Table 9 data written, 1 write selected plot file(s) and/or Table 9 data

(NSKPF(I), NSKPP(I), I=1, NSKPS):

NSKPF(I) is the no. of points (summary steps) to be skipped starting with data points NSKPP(I), i.e. every NSKPF(I) +1 data points are processed. A maximum of 10 pairs of skip sizes and starting points may be specified over the range of NPTS (NSKPP(I+1) > NSKPP(I) is assumed).

Example:      NSKPS = 3

    [ 9        1] [ 1        300] [ 8        322]

After the first set of data (t = 0 sec) is processed, the next 9 steps are skipped, and the following (11th) time step is processed. Thus, only each 10th step is processed (11, 21, 31, ..., 291). At time step 300, the number of steps to be skipped is reduced to one, and every other step is processed (300, 302, 304, ..., 320). Now, however, before processing data for step 322, the number to be skipped is increased to eight and skipping continues to the 329 step before processing data. Subsequently every 9th step is then processed until NPTS is reached. Thus, care must be exercised in choosing the boundaries at which the skip frequency is changed. A maximum of 2000 summary steps can be processed (saved) from the SUMMARY file.

These selected data are paired with the corresponding time data in ordered columns and written as text files. The files generated are acceptable as input by most plotting pages and spread sheet utilities.

PEAKF - Power peaking factor ( a multiplicative factor for the Table 9 data to get a hot channel power history), (default is 1.0)

The selected files and the corresponding card image time data are now in a convenient format for plotting, and the Table 9 data may be used directly in PARET. The limit for the PARET Table 9 data is 100 power-time pairs, and may be exceeded if more detail is required for plots.

## 5. THE PROPERTIES LIBRARY AND CODE TRANSPORTABILITY

The PARET code uses a binary properties library file which presented problems for export to other computers due to differences in format and word length on the various computer systems. The old library contained somewhat old data of unknown origin, and the pressure range covered was very broad. This library was limited to light water properties.

The original properties library has data at 27 pressures starting at 14.7 psia, the next value at 50.0 psia, and an upper value at 2500 psia, and interpolation to intermediate pressures gave a somewhat poor estimate for the corresponding saturation temperature.

A FORTRAN auxiliary code (PROPGENR) was developed to generate an updated properties library for research reactors with a more desirable range of system pressures. The current version of the binary library covers the range of 14.7 (psia 101.3kPa) to 50.0 psia (344.7kPa). A version of the code is also available for generating properties for heavy water applications. The binary library generated by this code is written on Unit 20 and is used as Unit 8 by the PARET/ANL code. The methods and parameters chosen for generating the library are annotated in the code. The code runs interactively with prompts for user input. The default options give the pressure range described above, but other ranges may be selected for the library.

While this revised library still contains uncertainties in the choices for the quality and slip ratio as a function of pressure, the capability of regenerating this library at least provides the means by which new approximations and data can be introduced, and the library can be transported to other computers.

In an effort to make the code more compatible for transport to other computer systems, the IBM assembly language free format input processor, CVI, has been replaced by a FORTRAN version.

The FORTRAN input processor routine imposes certain restrictions on the input and requires an additional scratch file (FORTRAN Unit 9) to contain each card image as it is processed. The card input following the card type number (a four or five digit number followed by a comma) must be blocked in fields of 12 columns beginning with column 7. Each field may contain either one floating point number (E12.5) format or up to two integers (2I6 format). All floating point numbers must include a decimal point. For mixtures of floating point numbers and single or odd numbers of integer entries, a blank field of 6 must be added with the single or last integer so that the next floating point number starts in the next proper field of 12. Each card can contain a maximum of 6 floating point numbers or 12 fixed point numbers through column 78. Embedded blank fields are allowed unless further restrictions are imposed and in some cases required as noted above. The card input format is further structured to some extent by card type (See sample problem input, Attachment 2). The initial integer entries on the 1000 series cards must be entered on card types 1001 and 1002, and the floating entries for the 1000 series start on 1003 and continue on additional cards in the series as needed. The 1112 card type must have 5 integer entries (with the odd number of integers a blank field of 6 must be imbedded) followed by 3 floating point numbers. The 4000 series cards must have pairs of entries consisting of one floating point number with a maximum of three sets per card. The 5N00 card(s) present special problems; a) the second entry may be either an integer number or a floating point number depending on the problem specified and b) the amount of data in the fixed format scheme requires a second card. Thus, if the second entry is an integer, the usual packing rules apply and five floating point numbers follow with three floating point numbers entered on an additional 5N00 card. However, if the second entry is floating point, a blank field of 6 must follow the integer entry and again five floating point entries follow but now the second card must contain four floating point entries. Embedded blank fields unless required are not allowed on the 5N00 cards. The remaining card types may be entered following only the general rules described above.

An example of the modified input format and the IAEA benchmark problem with SI units is shown as Attachment 2, and sample output for this case is provided in Attachment 3. With the exception of the double 5N00 cards, this fixed format can also be processed by the free format input processor. The PARET/ANL code is not maintained with the CVI input processor as an option, but rather as all FORTRAN 77 source code that can easily be converted for PC or UNIX compilers.

## 6. INPUT DESCRIPTION FOR PARET/ANL

Reference Document: “PARET - A Program for the Analysis of REactor Transients”  
by C. F. Obenchain, Report IDO-17282, Jan. 1969

The following is an item by item description of the input necessary to run the Argonne National Laboratory version of the PARET (reactor neutronics-hydro-dynamics-heat transfer) code. It is arranged in 16 sections plus a restart section, 6.0, and a tabulation of print increment selections, section 6.17. The user may choose between English or SI units. Variables with dimensions of length only are to be assumed to be in feet (ft) or meters (m). Units for all other dimensioned input variables are given below in both systems. It is assumed that the above reference is available to the user. References to this document by section and equation number are included in these descriptions. Consistency has been maintained between that document and these descriptions as much as possible. With the exception of Section 6.8, all data must be entered whether it is used or not.

### 6.0 Restart Data

First input card ( precedes the “\* title” card):

IRSTRT, IFREQ, ICHNG, NFILE, TTIME Format (4I6,E12.4)

IRSTRT	0	Initial problem (default)
	1	Restart problem
IFREQ	0 (or blank)	Write restart file every 1000 steps (default)
	n	Write restart file every n steps
ICHNG	0 (or blank)	No table changes (default)
	1	Time step data revision (Table 14 input follows)
	2	Time step and edits data revised (Table 14 and Table 16 input follows)
NFILE	blank	Default (IRSTRT=0)

12 or 14	Desired restart file number (IRSTRT=1) Restart data alternately written to units 12 and 14 (default 12)
TTIME	New time limit for transient (optional)

For the initial problem only a blank card is required if the default frequency for writing a restart file every 100 steps is desired.

For a restart problem, only IRSTRT=1 must be set. Restart data will be taken from unit 12 with no changes imposed, and no other input is required.

If TTIME is a non-zero, the transient time is reset to that value at restart. IFREQ may also be changed at restart.

If ICHNG=0, no further input data is required.

If ICHNG is non-zero, Table 14 data must be provided (even if no change is made in the time step data), and Table 16 data must be provided with ICHNG=2. The format for these tables is identical to the original 14000 and 16000 series PARET input data.

At this time no other input data may be changed at restart.

## 6.1 Title Line

A title line must precede each problem set of data. The format of the title line is as follows:

- (1) An asterisk (\*) in column 1.
- (2) An identifying title in columns 2 through 60 and centered on column 31.

## 6.2 General Information

The data lines immediately following the title line are of the format

→10YY, X<sub>1</sub>, X<sub>2</sub>, ..., X<sub>n</sub>

where YY=01, 02, ..., 99 and X<sub>i</sub>, i=1, 2, ..., n are the data (items)

- Notes:
- (a) Each line must contain at least one word (item) in addition to the line number.
  - (b) Data must be listed in required order (1 through 12 must be integers, and 13 through 47 must be floating point.)

<b><u>ITEM</u></b>	<b><u>FORTRAN VARIABLE</u></b>	<b><u>DESCRIPTION</u></b>
1	NCHN	The number of channels, NCHN, where $1 \leq  NCHN  \leq 4$ . This is the number of regions into which the core is subdivided. If NCHN is positive, the code assumes all input to follow will be in English units (ft, lb <sub>m</sub> , BTU, psi, °F). If negative, SI units are assumed (m, kg, J, Pa, °K). Power is always in megawatts. Internal calculations are carried out in English units but output is printed in the same units as the input data. Thus if SI units are used, input data are converted to English units after the input data is echoed and output data is converted back to SI units prior to printing.
2	NZ	The number of axial node points, NZ, where $1 \leq NZ \leq 21$ .
3	NR	The number of radial node points, NR, where $2 \leq NR \leq 44$ .
4	IGEOM	The geometry code: 0 for slab and 1 for cylindrical geometry.
5	IPROP	The operation code: 0 for power-level-specified and 1 for reactivity-specified (specified in Table 9).
6	IRXSWT	Vapor fraction and quality option. A zero indicates the assumption that subcooled $R = X = 0$ where R and X are the void fraction and quality, respectively. An entry of 1 allows the code to calculate values of R and X in both the sub-cooled and saturation regions.
7	IPOP	Moderator pressure code: 0 for the inlet pressure level being specified (see item 15), and 1 for outlet pressure level being specified.
8	KINTS	Kinetics time step parameter: 0 for reduce and expand, 1 for reduce only, -1 for reduce only and force printout and 2 for slow transients. In the zero option, the time step is reduced, when necessary, for the neutron kinetics calculations and then expanded to the input-specified or hydrodynamics-specified time step, whichever controls. An integral number of neutron kinetics time steps is contained in each input-specified or hydrodynamics-specified time step. In the 1 option, the time step is reduced for the neutron kinetics calculations, whenever necessary, and this same time step is used for the other calculations (thermal and hydrodynamic), as well. The -1 option is the same as the 1 option except that the printout is forced whenever time step reduction is effected. Reactivity feedback to the neutronics is computed in conjunction with the thermal-hydraulics calculations, and the first estimate of feedback at any particular time node is



necessarily based on a an extrapolation (since the value is needed prior to the thermal-hydraulics calculations). Therefore, at any time node at which only neutronics calculations are made (zero option), the value of the reactivity is obtained by extrapolation rather than direct calculation. Therefore, the zero option should be used with caution. A 2 option has been added for slow transients where poor stability in the power may be observed.

9	IDLYGP	The number of neutron delay groups, where $1 \leq \text{IDLYGP} \leq 15$ .
10	KINPRT	Kinetics print parameter: 0 for no intermediate printout, 1 for printout after every input-specified or NPOFQth (see 6.14 for NPOFQ) hydrodynamics-specified time step, and -1 for printout by subroutine TRANSS includes time, reactor power, reactivity, the maximum outlet flowrate of all channels, and average reactor period (averages over time step).
11	ISUPPR	Average temperature printout option. A zero yields no average temperature printout. For an entry of 1, average temperatures for each of the various regions (e.g. fuel, gap or insulator, and clad) are printed for each axial node of each channel at every time node. These temperatures represent the volumetric average temperatures averaged radially across each of the axial sections, and their printout precedes the detailed printout for the time node to which they apply.
12	MAXHCC	The maximum number of iterations through the heat transfer calculations at each axial node at any given time node. If $\text{MAXHCC} \leq 0$ , the problem will terminate when the heat code iterations exceed $ \text{MAXHCC} $ at any axial node. If $\text{MAXHCC} > 0$ and the heat code iterations exceed MAXHCC at any particular axial node, the problem continues, but the temperature printout at that node is accompanied by a star. Furthermore, a printout is forced in such cases.
13	POWER	Initial reactor power, in megawatts ( $>0$ ).
14	PF	Total volume of fuel in the core.
15	PRESUR	Operating pressure, in pounds per square inch (must be between 14.7 and 50.0 ) or Pascals ( $1.0\text{E}5$ and $3.4\text{E}5$ ) for current library.
16	ENTHIN	Enthalpy of inlet moderator in units of Btu/lb or J/kg ( $>0$ ). At the users option, the inlet moderator temperature ( $^{\circ}\text{C}$ or $^{\circ}\text{F}$ ) may be used in lieu of its enthalpy by entering the negative of that temperature. The code converts the temperature into the corresponding enthalpy and proceeds as usual. If the flow is negative or becomes negative (i.e., from top of core to bottom), the code senses this and estimates from the previous time step what the prescribed bottom value must

be to obtain the desired value of the enthalpy at the top. This can lead to inaccurate inlet values when rapid changes occur such as the commencement of boiling in the channel.

17	RS	Fuel pin radius or plate half-thickness ( including clad ).
18	RF	Fuel radius or half-thickness. Items 17 and 18 must be in agreement with the radial description given on the 3000 series lines (section 6.5).
19	RC	Radial distance to inner surface of the clad or, for slab geometry, the half-distance to the inner surface of the clad. This is the same as item 18, unless another material (gas gap, e.g.) lies between the fuel and clad.
20	PW	Plate width. Set to zero for cylindrical geometry.
21	FW	Fuel width. Set to zero for cylindrical geometry. Items 20 and 21 must both be greater than zero for slab geometry and item 20 greater than item 21.
22	AL	Active fuel length must be in agreement with the axial description given on the 4000 series lines (section 6.6).
23	ALDDIN	Inlet nonfueled section length ( $\geq 0$ ).
24	ALDDEX	Outlet nonfueled section length ( $\geq 0$ ). Items 23 and 24 refer to end sections of the fuel elements which contain no active fuel.
25	BBEFF	Effective delayed neutron fraction, $\beta$ ( $>0$ ).
26	EL	Prompt neutron generation time, $\Lambda$ , in seconds ( $>0$ ).
27	GRAV	Acceleration due to gravity, in units of ft/sec <sup>2</sup> or m/sec <sup>2</sup> ( $>0$ for upflow or $<0$ for downflow).
28	QW	Heat source description for moderator ( unitless and $>0$ ). This parameter is the fraction of the heat generated in the moderator multiplied by the ratio of the fuel meat volume to the moderator volume. See section 6.5 item 4 for the companion fraction(s), e.g. fraction of heat generated in the fuel.
29	TRANST	Transient time, in seconds ( $\geq 0$ ). This is the total reactor time interval ( not computation time ) over which it is desired to investigate the transient. If zero, only a steady-state calculation will be made.
30	RXXCON	A constant, $C_2$ ( unitless ), in the void volume generation Equation

(11) of the reference.

31	RXXEXP	An exponent, $n$ ( unitless ), in Equation ( 11 ) of the reference.
32	RHOREF	Moderator reference density, in units of $\text{lb/ft}^3$ or $\text{Kg/m}^3$ ( $>0$ ). This represents the density of the moderator at the initial reactor conditions. If $I_k = 3$ or $4$ , see section 6.7 item 2a, then this value is overridden within the code to assure accurate density difference calculations in natural convection. The new value is printed out to make the user aware of this.
33	GAMMA 0	
34	GAMMA 1	Coefficients for the fuel temperature feedback equation. See page 15, Equation 46, and page 42, items 34 - 38, in the reference document. See also section 6.7 item 4c of this document.
35	GAMMA 2	
36	GAMMA 3	
37	GAMMA 4	
38	DOPPN	The exponent, $n$ , used in the fuel temperature feedback equation referred to above.
39	EPS3	Upper limit for kinetics time step test, $Q_H$ ( unitless ). Recommend 0.001.
40	DNBQDP	Transient DNB heat flux. If a value of zero is entered here, the code uses steady-state DNB heat flux values calculated internal to the code (see Chapter III of reference document) for each axial node at each time node. If a nonzero value is entered, this value is used as the DNB heat flux for each axial node at each time node.
41	TAUUNB	Nucleate boiling bubble collapse time, $\tau_{NB}$ ( in seconds ). Consult the reference document.
42	TAUUTB	Transition boiling bubble collapse time, $\tau_{NB}$ ( in seconds ). Consult the reference document.
43	ALAMNB	Fraction of the clad surface heat flux, $\lambda_{NB}$ , which is utilized in producing vapor in the sub-cooled nucleate boiling region. Consult reference document. The fraction ( $1 - \lambda_{NB}$ ) would be used in heating the bulk liquid rather than in producing vapor.
44	ALAMTB	$\lambda_{TB}$ ; analogous to item 43, except that it applies to transition boiling.
45	ALAMFB	$\lambda_{FB}$ ; analogous to item 43, except that it applies to film boiling.

46	HTTCON	Natural convection heat transfer constant No. 1, see reference document. Also input of Nusselt No. with $IHT \geq 1$ ( 1112 card for loss-of-flow transients).
47	HTTEXP	Natural convection heat transfer constant No. 2, see reference document.

### 6.3 Additional General Information

<u>ITEM</u>	<u>FORTTRAN VARIABLE</u>	<u>DESCRIPTION</u>
		Data require for revisions that have been made to the PARET code are included in the 111X lines:  → 1111, PSUBC, FACT2(1), ....., FACT2(NCHN)
1a	PSUBC	Total cross sectional area of all flow channels in core.
2a	FACT2 (4)	Flux weighting factor; NCHN values entered on 1111 line. FACT2(I) is a factor along with the reactivity feedback weighting factor (section 6.7 item 5a) of the coolant energy and coolant energy removed which are outputs on the header page of major edits. FACT2(I) has no other affect on code calculations or results. Its physical significance is not clear and has been taken as unity in ANL calculations.  The PARET code supports a selection of heat transfer, flow instability, and DNB correlations and includes a tabulation of decay heat power based on the ANS curve for fission product decay heat. The code also provides a simulation of control rod reactivity insertion with rate and delay time settings, trip points for low flow and overpower, and leg lengths for natural convection effects. The required input for the 1112, 1113, and 1114 lines follow:  → 1112, IONEP, ITWOP, IMODE, ICHF, IHT, QAVE, ETA, CP
1b	IONEP	Single phase correlation flag 0 - original Dittus - Boelter 1 - Seider - Tate 2 - Petrukov - Popov ( Must have $IHT=0$ , see 5b )
2b	ITWOP	Two phase correlation flag

		0 - original Jens - Lottes 1 - McAdams 2 - Bergles - Rohsenow
3b	IMODE	Transient two phase scheme 0 - original model 1 - transition model 2 - DNB and flow instability correlations
4b	ICHF	0 - original DNB 1 - Bernath DNB 2 - Mirshak DNB 3 - Forgan FIR (Plate geometry only) 4 - CEA FIR (Plate geometry only) 5 - Lund DNB (Pin geometry only, see section 6.7, item 5b) 6 - Lund DNB with bowed pin (see section 6.7, item 6b)
5b	IHT	Single phase heat transfer subroutine use 0 - original 1 - revised, without entrance effects for h 2 - revised, with entrance effects for h
6b	QAVE	Average ( core ) heat flux used with ICHF = 3 & 4 [BTU/hr ft <sup>2</sup> or W/m <sup>2</sup> ]
7b	ETA	Bubble detachment parameter for ICHF = 3 (default 25)
8b	CP	Specific heat used with ICHF = 3 & 4 [BTU/lb - °F or J/kg - °K] (default 1.0 )
<b>→ 1113, RDRATE, TDLAY, POWTP, FLOTP, OPT, POW0</b>		
1c	RDRATE	Either rate for control rod movement ( with scram or withdrawal ) [ft/sec or m/sec] or a -1.0 (See Table 18 options)
2c	TDLAY	Delay time before rod starts in after trip [sec] (default 36000 sec )
3c	POWTP	Overpower trip point [MW] ( default 10000 MW )
4c	FLOTP	Low flow trip point [%] ( default 0.0% )
5c	OPT	Previous operation time of reactor - Used in decay heat level after scram [days] ( default 24.0 days )
6c	POW0	Previous operating power of the reactor - Used in decay heat power after scram [MW] ( default - initial power input for start up of transient )

→ 1114, HNCTOP

1d	HNCTOP	Height above reactor for natural convection effects.
2d	HNCBOT	Height below reactor for natural convection effects.
3d	REL_T	Lowest Reynolds number for laminar to turbulent transition (2300)
3d	RET_T	Highest Reynolds number for laminar to turbulent transition (6000)

If both values in line 1114 are 0.0, no output is printed for line 1114. These lengths would include the non-fueled section length, 6.2 items 23 and 24 and any plenum above or below the core.

#### 6.4 Thermal Properties of Fuel Element Materials

These data are input on a pair of lines in the form

Items 1 - 5, [ALPHA1 ( 3 ), ..., ALPHA5 ( 3 )] → 200X<sub>1</sub>,  $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$

Items 6 - 10, [BETA1 ( 3 ), ..., BETA5 ( 3 )] → 200X<sub>2</sub>,  $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$

#### Description

Notes:

- either
- (a) There is one pair of lines per material, the number of materials being two (e.g., fuel and clad) or three
  - (b)  $X_2 = X_1 + 1$
  - (c)  $X_1 = 1$  for the first material, 3 for the second, and 5 for the third
  - (d) The  $\alpha_n$ , ( $n = 1, 2, \dots, 5$ ) are the thermal conductivity coefficients of the material for an equation of the form

$$k_{n+1/2}^m = \alpha_1 T^2 + \alpha_2 T + \alpha_3 + \alpha_4 / T$$

where

$$T = \left( \frac{u_n^m + u_{n+1}^m}{2} \right) + \alpha_5$$

$u_n^m$  is the temperature of the material at the  $n^{\text{th}}$  radial node at the  $m^{\text{th}}$  time node, in  $^{\circ}\text{F}$  or  $^{\circ}\text{C}$ .  $k_{n+1/2}^m$  is the thermal conductivity of the material between the  $n^{\text{th}}$  and  $n + 1^{\text{st}}$  radial nodes, in units of

$$\frac{\text{Btu}}{\text{hr} - \text{ft} - ^{\circ}\text{F}} \text{ or } \frac{\text{W}}{\text{m} - ^{\circ}\text{K}}$$

(e) The  $\beta_n$  (  $n = 1, 2, \dots, 5$  ) are the volumetric heat capacity coefficients of the material for an equation of the form

$$g_{n+1/2}^m = \beta_1 T^2 + \beta_2 T + \beta_3 + \beta_4 / T$$

where

$$T = \left( \frac{u_n^m + u_{n+1}^m}{2} \right) + \beta_5$$

$g_{n+1/2}^m$  is the volumetric heat capacity of the material between the  $n^{\text{th}}$  and  $n + 1^{\text{st}}$  radial nodes, in units of

$$\frac{\text{Btu}}{\text{ft}^3 - ^{\circ}\text{F}} \text{ or } \frac{\text{J}}{\text{m}^3 - ^{\circ}\text{K}}$$

## 6.5 Radial or Half-Plate Thickness Description

The radial description refers to cylindrical geometry and half-plate thickness (symmetry assumed) to slab geometry. Each line is of the form

**ITEM**      **FORTRAN**  
**VARIABLE**

**DESCRIPTION**

→ 3XXX, Y, I, J, Z

where XXX = 001, 002, ..., 999

- |   |       |   |
|---|-------|---|
| 1 | AINCR | Y is the radial increment length, ( >0 )                              |
| 2 | KK    | I is the radial node out to which the increment applies ( integer and |

>0 )

- |   |       |  |
|---|-------|--|
| 3 | ICOMP | J is the composition code represented by one of the three integers 1, 2 or 3. The composition code begins at the center; i.e., the fuel is composition 1, the next material is composition 2, etc. The clad is the last composition ( 2 or 3 ) and the maximum number of materials is 3. |
| 4 | QR    | Z is the radial source description ( $\geq 0$ ). This is the fraction of heat generated in this composition. The 3000 card fractions together with that designated for the moderator (used in section 6.2 item 28) should sum to 1.0.  |

Notes:

- (a) On line 3001 (XXX=001 ) the first I -1 radial increment will be represented (  $I > 2$  ) all of length Y, composition J ( see 2000 series lines ), and radial heat source magnitude Z.
- (b) On each succeeding line the Y, I, J, and Z values apply to radial increments following those covered by the previous line, up to I - 1 from the new line.
- (c) When either the radial increment, the composition code, or the radial source description changes from one node point to the next, a new line must be input for the next node point or node points.
- (d) The 3000 - series lines describe the pin or plate from the centerline to the outer surface of the clad. The node point at the fuel centerline is node point number one ( not zero ).
- (e) The sum of the increment lengths between successive pairs of node points must be equal to the pin radius or plate half-thickness given in section 6.2 item 17; also, the dimensions given in items 18 and 19 must bear a correct correspondence to the dimensions given on these 3000 - series lines.

## 6.6 Axial Description

<u>ITEM</u>	<u>FORTTRAN</u> <u>VARIABLE</u>
-------------	------------------------------------

DESCRIPTION

→ 4XXX, Y<sub>1</sub>, I<sub>1</sub>, Y<sub>2</sub>, I<sub>2</sub>, ..., Y<sub>i</sub>, I<sub>i</sub>, ...Y<sub>n</sub>, I<sub>n</sub>



where XXX = 001, 001, ..., 999

- |   |         |   |
|---|---------|---|
| 1 | DZ (21) | $Y_i$ is the axial region length ( $>0$ )   |
| 2 | KJ      | $I_i$ is the region through which the length $Y_i$ , applies, subject to the conditions |

$$I_1 \geq 1 \text{ and } I_i \geq I_{i-1}$$

Notes:

(a) If there are NZ axial regions, there will be NZ axial node points and NZ -1 axial increments,  $\Delta Z_j$ , as the illustration in Fig. 1. Except for the node points 1 and NZ, all axial node points are located at the center of regions I of length Y. Node 1, however, is located at the one end of the fuel and node NZ at the other end of the fuel, rather than at the center of regions 1 and NZ. Thus

$$\begin{aligned}\Delta Z_1 &= R_1 + 1/2 R_2 \\ \Delta Z_j &= 1/2 (R_j + R_{j+1}); \quad 1 < j < \text{NZ}-1 \\ \Delta Z_{\text{NZ}-1} &= 1/2 R_{\text{NZ}-1} + R_{\text{NZ}}\end{aligned}$$

where  $\Delta Z_j$  represents the distance between node point J and J + 1, and  $R_j$  represents the length of region j. A maximum of 20 axial regions is allowed.

(b) The 4000 - series lines describe the axial spacing in the active fuel only, beginning at the bottom of the active fuel and proceeding to the top.

(c) The sum of the axial increments must be equal to the active fuel length given in section 6.2 item 22.

(d) The information,  $Y_i$  and  $I_i$ , must be in pairs; a pair may not be split between two lines.

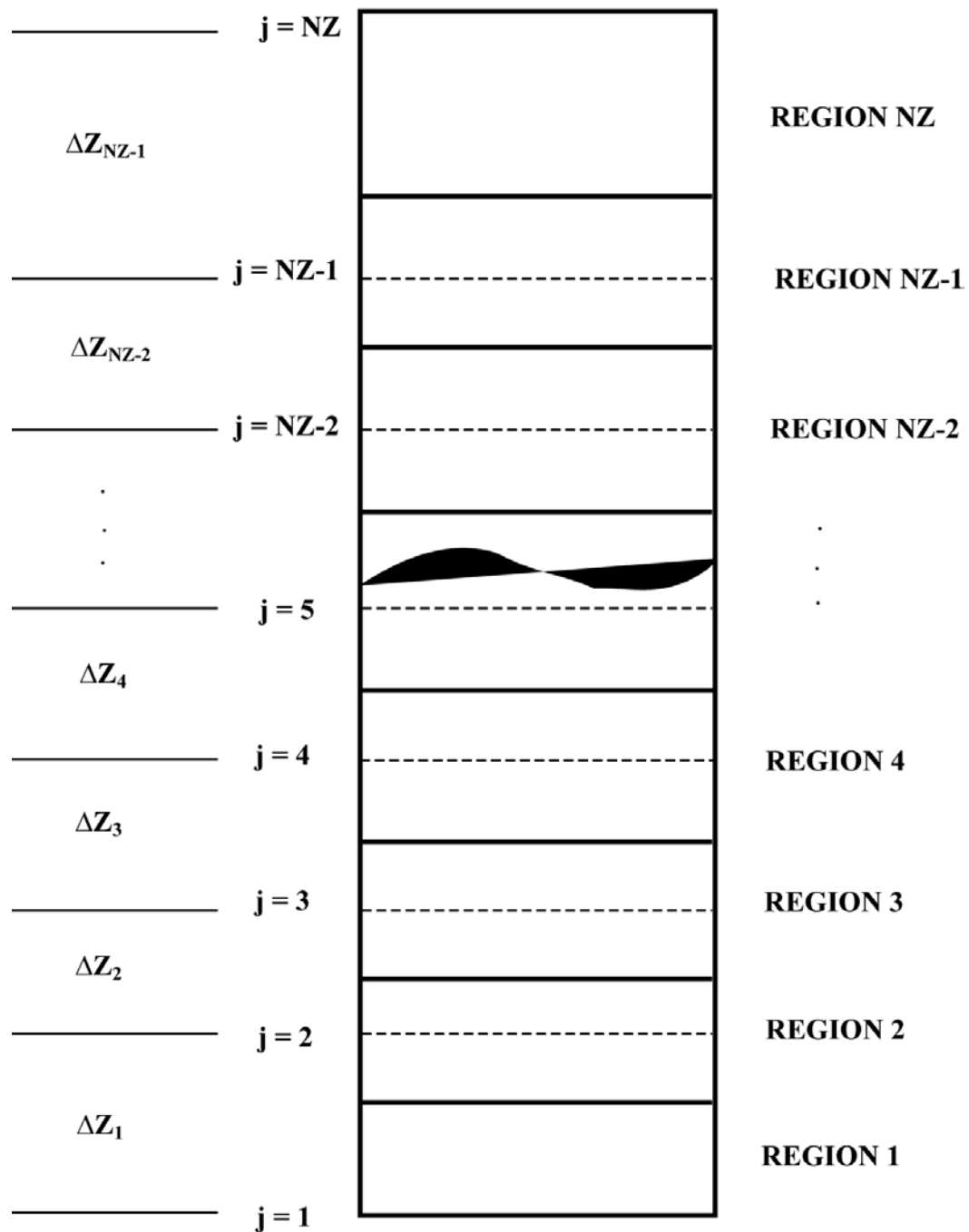


Figure 1. Axial Sectoring of Fuel Rod/Plate Illustrating Relationship Between Regions, Spatial Nodes and Axial Increments

## 6.7 Individual Channel Information

<u>ITEM</u>	<u>FORTTRAN VARIABLE</u>	<u>DESCRIPTION</u>
		The data for each channel are input in the form  → <b>5k00, I<sub>k</sub>, L<sub>k</sub>, X<sub>k1</sub>, X<sub>k2</sub>, X<sub>k3</sub>, X<sub>k4</sub>, X<sub>k5</sub>, X<sub>k6</sub>, X<sub>k7</sub>, X<sub>k8</sub></b>
1a	k	k = 1 for the first channel, 2 for the second, etc. If a problem includes several channels, some of which are flow-forced and some pressure-drop-forced, the flow-forced channels must be numbered lower than the pressure-drop-forced channels unless the pressure drop is obtained from Table 12. This is necessary because the pressure drop across the flow-forced channels must be calculated before it can be imposed across the pressure-drop-forced channels.
2a	IFLOW(4)	I <sub>k</sub> is the flow parameter.  (a) 1 for flow-forced channel (flow is specified in Table 10). (b) 2 for pressure-drop-forced-channel (pressure drop is specified in Table 12 or in item 3a (b) below). (c) 3 for buoyant forced flow (in all channels) with pump coast down superimposed from Table 17. Initial flow rate is computed from pressure drop given in next entry. (d) 4, same as 3 except initial flow taken from value at zero time in Table 10.
3a	DELP(4)	L <sub>k</sub> is  (a) Zero if I <sub>k</sub> = 1 (b) Either the pressure drop (lb / in. <sup>2</sup> or Pascals), or a channel number if I <sub>k</sub> = 2 (must be positive or nonzero). In a former case, the pressure drop as a function of time is given in Table 12, but the initial pressure drop must be given here. In the latter case, the channel number given is the number of a flow-forced channel across which the pressure drop is calculated as function of time. This same pressure drop is then automatically imposed across the pressure-drop-forced channel at corresponding times. The initial pressure drop is specified by DELP for I <sub>k</sub> = 3. If I <sub>k</sub> = 4 the floating point number provided is not used but a zero value should not be specified (DELP ≠ 0.0).
4a	RN(4)	X <sub>k1</sub> is the radial distance from the center of the pin to the node in the center of the water channel, or the analogous quantity for slab geometry. Must be positive, nonzero, and greater than the pin radius (or slab half-thickness).

- 5a      BM(4)       $X_{k2}$  is the reactivity feedback weighting factor for channel k. It is convenient to set this number equal to the volume fraction of the core represented by channel k (one number for each of NCHN channels). In this case, the sum of the  $X_{k2}$  summed over the NCHN channels must be unity.
- 6a      ALOSCN(4)       $X_{k3}$  is an unrecoverable loss coefficient for abrupt change in the area at the inlet to the channel k ( $> 0$ ). This change is the proportionality constant between the pressure change across the abrupt area change and the fluid kinetic energy. See reference document.
- 7a      ALOSCX(4)       $X_{k4}$  is the outlet loss coefficient analogous to  $X_{k3}$  in item 6a ( $> 0$ ).
- 8a      SIGIN(4)       $X_{k5}$  is the inlet area ratio ( $> 0$ ). This is the ratio of the channel area to the area of the associated inlet plenum. See reference document.
- 9a      SIGEX(4)       $X_{k6}$  is the outlet area ratio ( $> 0$ ). This is the ratio of the channel area to the area of the associated outlet plenum.
- 10a      DVOID(4)       $X_{k7}$  is an overall density/void coefficient. The product of  $X_{k7}$  and  $Z_{kXX}$  given in item 3c below is the value of the local density/void coefficient at the axial node XX of channel k. The product must be in \$/% of core voided.
- 11a      DTMP(4)       $X_{k8}$  is the coolant temperature coefficient. The product of  $X_{k8}$  and  $TEMPC_{kXX}$  given in item 5c below is the value of the local coolant temperature coefficient at axial node XX of channel k. The product must be  $^{\circ}F$  or  $^{\circ}C$ .

The 5k01 lines are input in the format

**→ 5k01,  $L_I$ ,  $L_E$ ,  $(De)_I$ ,  $(De)_E$  [,  $P_N$ ,  $P_B$ ]**

where

- 1b      ALPPIN(4)       $L_I$  represents the length of the inlet plenum, ( $\geq 0$ ).
- 2b      ALPPEX(4)       $L_E$  represents the length of the outlet plenum, ( $\geq 0$ ).
- 3b      DEEIN(4)       $(De)_I$  represents the inlet plenum equivalent diameter, ( $\geq 0$ ).
- 4b      DEEEX(4)       $(De)_E$  represents the outlet plenum equivalent diameter, ( $\geq 0$ ). Items (1), (2), (3), and (4) refer to the inlet and outlet plena to and from the coolant flow channels
- 5b      PITCH(4)       $P_N$  - nominal pitch-to-diameter ratio (Only with ICHF=5 or 6)

6b BOWPTCH(4) PB – bowed pitch-to-diameter ratio (Only with ICHF=6, 1112 Card)

The remaining 5000 - series lines ( $XX \geq 02$ ) are in the format

→ **5kXX, Y<sub>kXX</sub>, Z<sub>kXX</sub>, DOPPLR<sub>kXX</sub>, TEMPC<sub>kXX</sub>**

where

1c k is defined in section 6.7 item 1a above. XX is 02 for the first line, 03 for the second, etc.

2c PFQ(84) Y<sub>kXX</sub> is the axial source description for axial node (XX-1). This parameter is the value of the ratio of the local neutron flux to the core-average neutron flux.

3c VOIDVC(84) Z<sub>kXX</sub> is the moderator density feedback weighting factor for axial node (XX-1). The product of Z<sub>kXX</sub> and X<sub>k7</sub> and its units are discussed in section 6.7 item 10a above.

4c DOPPLR(84) DOPPLR<sub>kXX</sub> represents the D<sub>j,k</sub> parameter in the feedback fuel temperature equation [refer to Equation (46) of reference document.].

$$(R_D)_{j,k} = D_{j,k} \left[ \gamma_0 + \gamma_1 (\bar{u}_M + \gamma_4) + \gamma_2 (\bar{u}_M + \gamma_4)^2 + \gamma_3 (\bar{u}_M + \gamma_4)^n \right]$$

The units of the products  $D_{j,k} \times \gamma_i$  ( $i = 0, 1, 2, 3$ ) must be consistent with the units of  $(R_D)_{j,k}$ , which is dollars. In this equation the units of the mean temperature of the fuel,  $\bar{u}_M$ , may be in units of °F or °C and  $\gamma_4$  may be used to convert to degrees R or K.

5c TEMPC(84) TEMPC<sub>kXX</sub> is the coolant temperature feedback weighting factor for axial node (XX-1). See section 2 (5000 series cards).

## 6.8 Delayed Neutron Information

[must not be included for a power-level-specified problem, section 6.2 item 5]

<u>ITEM</u>	<u>FORTTRAN</u> <u>VARIABLE</u>
-------------	------------------------------------

DESCRIPTION

This information is input in the following format:

→ 6XXX, Y<sub>1</sub>, Z<sub>1</sub>, Y<sub>2</sub>, Z<sub>2</sub>, ..., Y<sub>i</sub>, Z<sub>i</sub>, ..., Y<sub>n</sub>, Z<sub>n</sub>

where XXX is 001 for the first line, 002 for the second, etc.

- |   |           |  |
|---|-----------|--|
| 1 | FRACT(15) | Y <sub>i</sub> is the delayed neutron fraction for group i<br>$Y_i = \beta_i/\beta$ (>0)                               |
| 2 | DECAY(15) | Z <sub>i</sub> is the delayed neutron decay constant for group i (positive, nonzero, and units of sec <sup>-1</sup> ). |

- Notes:
- (a) Number of pairs, n, is given in section 6.2 item 9 as IDLYGP.
  - (b) The information must be in pairs; a pair may not be split between two lines.
  - (c) The sum of all Y<sub>i</sub> must be in unity; i.e.,

$$\sum_{i=1}^n Y_i = 1.0, \text{ or } \sum_{i=1}^n \beta_i = \beta$$

## 6.9 Power or Reactivity Versus Time (Table 9)

**ITEM**      **FORTTRAN**  
**VARIABLE**

**DESCRIPTION**

This table is input in the following format:

1a          NTBL9      →9000, N

where N is the number of pairs of entries in the table,  $2 \leq N \leq 100$ .

The succeeding lines are of the form

→9XXX, Y<sub>1</sub>, Z<sub>1</sub>, Y<sub>2</sub>, Z<sub>2</sub>, ..., Y<sub>i</sub>, Z<sub>i</sub>, ..., Y<sub>n</sub>, Z<sub>n</sub>

where XXX is 001 for the first line, 002 for the second, etc.

1b          REACC(100)      Y<sub>i</sub> is the  
                                  (a) Power (in megawatts) if section 6.2 item 5 is zero  
                                  (b) Reactivity (in dollars) if section 6.2 item 5 is unity  
                                  This is the reactivity which is externally inserted (i.e., not compensated reactivity). The first reactivity entry in the table, Y<sub>1</sub>, must be negative or zero.

2b          TBL9(100)      Z<sub>i</sub> is the time (in seconds) associated with Y<sub>i</sub>.

Notes:

- (a) The information must be in pairs; a pair may not be split between two lines.
- (b) The data must be in ascending order ( $Z_i \leq Z_{i+1}$ ) with  $Z_1 = 0$  and the last value of  $Z$  greater than the total transient time given in section 6.2 item 29.
- (c) There must be at least two pairs of table entries.

#### 6.10 Moderator Inlet Mass Velocity Versus Time (Table 10)

<u>ITEM</u>	<u>FORTTRAN</u> <u>VARIABLE</u>	<u>DESCRIPTION</u>
-------------	------------------------------------	--------------------

This table is input according to the following format:

1a      NTBL10      →10000, N

where N is the number of pairs of entries in the table,  $2 \leq N \leq 100$ .

Subsequent lines are in the form

→10XXX,  $Y_1, Z_1, Y_2, Z_2, \dots, Y_n, Z_n$

where XXX is 001 for the first line, 002 for the second, etc.

1b      AMFRIN(100)       $Y_i$  is the inlet mass velocity ( $\text{lb}_m/\text{hr}/\text{ft}^2$  or  $\text{Kg}/\text{s}/\text{m}^2$ )

2b      TBL10(100)       $Z_i$  is the time (in seconds) associated with  $Y_i$ .

Notes:

- (a) The information must be in pairs; a pair may not be split between two lines.
- (b) The data must be in ascending order ( $Z_i \leq Z_{i+1}$ ) with  $Z_1 = 0$  and the last value of  $Z$  greater than the total transient time given in section 6.2 item 29.
- (c) There must be at least two pairs of table entries.

### 6.11 Percent Linear Thermal Expansion of the Clad Versus Temperature (Table 11)

<u>ITEM</u>	<u>FORTRAN VARIABLE</u>	<u>DESCRIPTION</u>
-------------	-----------------------------	--------------------

This table is input in the following format:

1a      NTBL11      →11000, N

where N is the number of pairs of entries in the table,  $2 \leq N \leq 100$ .

Subsequent lines are of the form

→11XXX, Y<sub>1</sub>, Z<sub>1</sub>, Y<sub>2</sub>, Z<sub>2</sub>, ..., Y<sub>n</sub>, Z<sub>n</sub>

where XXX is 001 for the first line, 002 for the second, etc.

1b      YYCLAD(100)      Y<sub>i</sub> is the percent linear thermal expansion of the clad (%).

2b      YCTEMP(100)      Z<sub>i</sub> is the temperature (°R or °K ) associated with Y<sub>i</sub>.

Notes:

(a) The information must be in pairs; a pair may not be split between two lines.

(b) The data must be in ascending order ( $Z_i \leq Z_{i+1}$ ) and must include the maximum and minimum average temperatures of the clad to be encountered throughout the course of the problem.

(c) There must be at least two pairs of table entries.

### 6.12 Total Pressure Drop Versus Time (Table 12)

<u>ITEM</u>	<u>FORTRAN VARIABLE</u>	<u>DESCRIPTION</u>
-------------	-----------------------------	--------------------

This table is input in the following format:

1a      NTBL12      →12000, N

where N is the number of pairs of entries in the table,  $2 \leq N \leq 100$ .

Subsequent lines are of the form

→12XXX, Y<sub>1</sub>, Z<sub>1</sub>, Y<sub>2</sub>, Z<sub>2</sub>, ..., Y<sub>n</sub>, Z<sub>n</sub>

where XXX is 001 for the first line, 002 for the second line, etc.

1b      PRESSP(100)      Y<sub>i</sub> is the total pressure drop,  $\Delta p_T$  [psi or N/m<sup>2</sup> (Pascal)], across the



channel.

2b TBL12(100)  $Z_i$  is the time (in seconds) associated with  $Y_i$ .

Notes:

- (a) The information must be in pairs; a pair may not be split between two lines.
- (b) The data must be in ascending order ( $Z_i \leq Z_{i+1}$ ) with  $Z_1 = 0$  and the last value of  $Z$  greater than the total transient time given in section 6.2 item 29.
- (c) There must be at least two pairs of table entries.

### 6.13 Table of Time Increment Versus Time (Table 14)

-[may be modified for restarts]

**ITEM**      **FORTRAN**  
**VARIABLE**

**DESCRIPTION**

This table is input in the following format:

1a NTBL14 →14000, N

where N is the number of pairs of entries in the table,  $2 \leq N \leq 10$ .

Subsequent lines are of the form

→14XXX,  $Y_1, Z_1, Y_2, Z_2, \dots, Y_n, Z_n$

where XXX is 001 for the first line, 002 for the second, etc.

1b TINCRR(10)  $Y_i$  is the time increment (in seconds)

2b TBL14(10)  $Z_i$  is the reactor time at which time-step increment is to go into effect ( $Z_1$  must be zero).

Notes:

- (a) The information must be in pairs; a pair may not be split between two lines.
- (b) The data must be in ascending order ( $Z_i \leq Z_{i+1}$ ), with  $Z_1 = 0$ . There must be at least two pairs of table entries.
- (c) If two pairs of zeros are entered into Table 14, the code will calculate its own time step on the basis of the hydrodynamics.

## 6.14 Table of Print Frequency Versus Time (Table 16)

- [may be modified for restarts]

<u>ITEM</u>	<u>FORTTRAN</u> <u>VARIABLE</u>	<u>DESCRIPTION</u>
		This table is input in the format:
1a	NTBL16	→16000, N
		where N is the number of sets of entries in the table, $1 \leq N \leq 10$ .
		Subsequent lines are of the form
		→16XXX, Y <sub>1</sub> , M <sub>1</sub> , Z <sub>1</sub> , Y <sub>2</sub> , M <sub>2</sub> , Z <sub>2</sub> , ..., Y <sub>n</sub> , M <sub>n</sub> , Z <sub>n</sub>
		where XXX is 001 for the first line, 002 for the second, etc.
1b	TOPFQ(10)	Y <sub>i</sub> is the print time increment (in seconds) for major output edits.
2b	NPOFQ(10)	M <sub>i</sub> is the frequency of intermediate printout (i.e., every M <sub>i</sub> steps).
3b	TBL16(10)	Z <sub>i</sub> is the reactor time at which print time increment is to go into effect (Z <sub>1</sub> must be zero).

Notes:

- (a) Major output edits will occur at  
0, Y<sub>1</sub>, 2Y<sub>1</sub>, ..., Z<sub>1</sub>, Z<sub>1</sub> + Y<sub>2</sub>, Z<sub>1</sub> + 2Y<sub>2</sub>, ..., Z<sub>2</sub>, Z<sub>2</sub> + Y<sub>3</sub>, ..., etc.
- (b) Intermediate output edits will occur ever M<sub>i</sub> steps when Z<sub>i</sub> < time < Z<sub>i+1</sub>.\*\*\*
- (c) The information must be in triplets; a triplet may not be split between two lines.
- (d) The data must be in ascending order (Z<sub>i</sub> ≤ Z<sub>i+1</sub>), with Z<sub>1</sub> = 0.
- (e) In addition to the output indicated in section 6.2 item 10, the minimum burnout ratio, the minimum bubble detachment parameter (ETA), the maximum temperature in the coolant, clad, and fuel, and the nucleate (1), transition (2), film (3), and bulk (4) boiling point indicators are printed at each intermediate output time by subroutine PRNTMP.

---

\*\*\* See the attached tabulation of increment choices by time step size

### 6.15 Table of Pump Mass Velocity Fraction Versus Time (Table 17)

<u>ITEM</u>	<u>FORTTRAN VARIABLE</u>	<u>DESCRIPTION</u>
		This table is input in the format
1a	NTBL17	→17000, N
		where N is the number of pairs of entries in the table, $2 \leq N \leq 20$ .
		Subsequent lines are of the form
		→17XXX, Y <sub>1</sub> , Z <sub>1</sub> , Y <sub>2</sub> , Z <sub>2</sub> , ..., Y <sub>n</sub> , Z <sub>n</sub>
		where XXX is 001 for the first line, 002 for the second, etc.
1b	FLOWRT(20)	Y <sub>i</sub> is the mass velocity fraction of the coolant in the channel to its initial value (Y <sub>1</sub> must be 1.0).
2B	TBL17(20)	Z <sub>i</sub> is the reactor time corresponding to Y <sub>i</sub> (Z <sub>1</sub> must be zero).
	Notes:	(a) The information must be in pairs; a pair may not be split between two lines. (b) The data must be in ascending order ( $Z_i \leq Z_{i+1}$ ), with $Z_1 = 0$ . (c) There must be at least two pairs of table entries. (d) This table is used in conjunction with I <sub>k</sub> = 3 or 4 only, as specified in section 6.7 item 2a.

### 6.16 Table of Rod Worth Versus Rod Location or Lapsed Time (Table 18)

<u>ITEM</u>	<u>FORTTRAN VARIABLE</u>	<u>DESCRIPTION</u>
		This table is input in the format:
1a	NTBL18	→18000, N
		where N is the number of pairs of entries in the table, $2 \leq N \leq 20$ .
		Subsequent lines are of the form
		→18XXX, Y <sub>1</sub> , Z <sub>1</sub> , Y <sub>2</sub> , Z <sub>2</sub> , ...Y <sub>n</sub> , Z <sub>n</sub>

where XXX is 001 for the first line, 002 for the second, etc.

- |    |            |  |
|----|------------|--|
| 1b | RODWTH(20) | $Y_i$ is the reactivity (\$) associated with the control rod. Negative values should be entered for rod insertion.   |
| 2b | RODLOC(20) | $Z_i$ is either the rod position (ft or m) corresponding to $Y_i$ where the rate of motion is specified by RDRATE in Card 1113, or the time (sec) corresponding to $Y_i$ with RDRATE set to $-1.0$ in Card 1113. If time data is used, the values are relative to the start of rod motion. |

Notes:

- (a) The information must be in pairs; a pair may not be split between two lines.
- (b) There must be at least two pairs of table entries.

### 6.17 Print Edit - Increment Selection (for Table 16)

<u>Time Step,</u> seconds	<u>Major Edit</u> <u>Increment's</u>	<u>Number of Minor Edits per Increment</u>				
Table 14	$Y_i$	$M_i$				
		1	5	10	20	50
0.05	2.0	40	8	4	2	-
	1.0	20	4	2	1	-
	0.5	10	2	1	-	-
0.01	1.0	100	20	10	5	2
	0.5	50	10	5	2	1
	0.1	10	2	1	-	-
0.005	1.0	200	40	20	10	4
	0.5	100	20	10	5	2
	0.1	20	4	2	1	-
0.001(1 ms)	1.0	1000	200	100	50	20
	0.5	500	100	50	25	10
	0.1	100	20	10	5	2
	0.05	50	10	5	2	-
0.0005	0.5	1000	200	100	50	20
	0.1	200	40	20	10	4
	0.05	100	20	10	5	2
	0.01	20	4	2	1	-
0.0001	0.1	1000	200	100	50	20
	0.05	500	100	50	25	10
	0.01	100	20	10	5	2
	0.005	50	10	5	2	1
0.00005	0.05	1000	200	100	50	20
	0.01	200	40	20	10	4
	0.005	100	20	10	5	2
	0.001	20	4	2	1	-
0.000001(1 $\mu$ s)	0.001	1000	200	100	50	20
	0.0005	500	100	20	25	10
	0.0001	100	20	10	5	2
	0.00005	50	10	5	2	-
0.0000005	0.0005	1000	200	100	50	20
	0.0001	200	40	20	10	4
	0.00005	100	20	10	5	2
	0.00001	20	4	2	1	-

## APPENDIX

### Conversion Factors:

Pressure [psia] \* 6.89476  $\rightarrow$  [ kPa ]

Enthalpy [Btu/lb] \* 2.326090  $\rightarrow$  [ kJ/kg ]

Specific Vol. [ft<sup>3</sup>/lbm] \* 6.2428E-02  $\rightarrow$  [m<sup>3</sup>/kg]

Mass Flow Rate [lb/hr ft<sup>2</sup>] \* 1.35623E-03  $\rightarrow$  [kg s\*m<sup>2</sup>]

Heat Flux [Btu/ hr ft<sup>2</sup>] \* 3.15459  $\rightarrow$  [W/m<sup>2</sup>]

Heat Transfer Coefficient [Btu/ hr ft<sup>2</sup> °F] \* 5.678263  $\rightarrow$  [W/m<sup>2</sup> K]

Conductivity [Btu/ hr ft °F] \* 1.730735  $\rightarrow$  [W/mK]

Volumetric Heat Capacity ( $\rho C_p$ ) [Btu/ ft<sup>3</sup> °F] \* 6.70661E+04  $\rightarrow$  [J/m<sup>3</sup>K]

Length [ft] \* 0.3048  $\rightarrow$  [m]

## ATTACHMENT 1

### Change to the PARET Program

Changes have been made to the PARET program enabling it to calculate the coolant energy removal. One additional constant,  $P_c$ , must be read in on card number 1111 in floating point format. This card follows the 100I cards and precedes the 200I cards in the data deck. The value of  $P_c$  is printed on the first page of output.

The coolant energy removal is calculated for each time step from the following equation:

$$CER = \frac{1}{P_c} \int_0^t \sum_{I=1}^{NC} [ENT_{XI} * MFR_{XI} - ENT_{OI} * MFR_{OI}] dt$$

where

NC	--	number of channels
ENT <sub>XI</sub>	--	exit enthalpy, channel I
MFR <sub>XI</sub>	--	exit mass flow rate, channel I
ENT <sub>OI</sub>	--	inlet enthalpy, channel I
MFR <sub>OI</sub>	--	inlet mass flow rate, channel I

The resulting coolant energy removal (mw-sec) is printed just below the value of the energy every time a full time step printout occurs.

## ATTACHMENT 2

### Sample Input for the 10 MW IAEA Benchmark Reactor - HEU Model:

0							
* PARET:	HEU Benchmark	2 Channel	\$1.50/0.5s	Ramp Insertion	Pert.	Weighting	
1001,	-2	21	7	0	1	1	
1002,		0	6	-1	0	10	
1003,	1.0000-6	0.01062214		1.70000+5	1.58650+5	6.35000-4	
1004,	2.5500-4	2.5500-4		6.6500-2	6.3000-2	0.6000	0.0
1005,	0.0	0.0076071		55.960-6	9.80664	0.00975	
1006,	0.80	0.8000		1.0	993.20	0.0	
1007,	3.60000-5	0.0		0.0	0.0	1.0	0.001
1008,	0.0	0.0005		0.001	0.03	0.05	0.05
1009,	1.4	0.33					
1111,	0.0857927	1.0		1.0			
1112,	1	1	1	0	0	4.0350+5	
1113,	1.2	0.025		12.0	0.0		
1114,	0.0	0.0					
2001,	0.0	0.0		158.0	0.0	0.0	
2002,	0.0	1.0670+3		2.0721+6	0.0	0.0	
2003,	0.0	0.0		180.0	0.0	0.0	
2004,	0.0	1.2420+3		2.0691+6	0.0	0.0	
3001,	6.3750-5	5	1	0.955			
3002,	1.9000-4	7	2	0.0			
4001,	2.85714-2	21					
5100,	1	0	1.7500-3	0.00181	0.55	0.65	1.0
5100,	1.0	0.2992		1.6459-2			
5101,	0.0	0.0		0.3048	0.3048		
5102,	0.1885	0.3617		1.0	0.4595		
5103,	0.7172	0.5596		1.0	0.4136		
5104,	1.0530	0.6938		1.0	0.5340		
5105,	1.3674	0.8260		1.0	0.7074		
5106,	1.6541	0.9585		1.0	0.8934		
5107,	1.9073	1.0862		1.0	1.0740		
5108,	2.1218	1.2021		1.0	1.2376		
5109,	2.2934	1.2999		1.0	1.3751		
5110,	2.1484	1.3740		1.0	1.4790		
5111,	2.4945	1.4202		1.0	1.5436		
5112,	2.5200	1.4358		1.0	1.5656		
5113,	2.4945	1.4202		1.0	1.5436		
5114,	2.1484	1.3740		1.0	1.4790		
5115,	2.2934	1.2999		1.0	1.3751		
5116,	2.1218	1.2021		1.0	1.2376		
5117,	1.9073	1.0862		1.0	1.0740		
5118,	1.6541	0.9585		1.0	0.8934		
5119,	1.3674	0.8260		1.0	0.7074		
5120,	1.0530	0.6938		1.0	0.5340		
5121,	0.7172	0.5596		1.0	0.4136		
5122,	0.1885	0.3617		1.0	0.4595		
5200,	1	0	1.7500-3	0.99819	0.55	0.65	1.0
5200,	1.0	0.2992		1.6459-2			
5201,	0.0	0.0		0.3048	0.3048		
5202,	0.1122	0.3617		1.0	0.4595		



5203,	0.4269	0.5596	1.0	0.4136			
5204,	0.6268	0.6938	1.0	0.5340			
5205,	0.8139	0.8260	1.0	0.7074			
5206,	0.9846	0.9585	1.0	0.8934			
5207,	1.1353	1.0862	1.0	1.0740			
5208,	1.2630	1.2021	1.0	1.2376			
5209,	1.3651	1.2999	1.0	1.3751			
5210,	1.4395	1.3740	1.0	1.4790			
5211,	1.4848	1.4202	1.0	1.5436			
5212,	1.5000	1.4358	1.0	1.5656			
5213,	1.4848	1.4202	1.0	1.5436			
5214,	1.4395	1.3740	1.0	1.4790			
5215,	1.3651	1.2999	1.0	1.3751			
5216,	1.2630	1.2021	1.0	1.2376			
5217,	1.1353	1.0862	1.0	1.0740			
5218,	0.9846	0.9585	1.0	0.8934			
5219,	0.8139	0.8260	1.0	0.7074			
5220,	0.6268	0.6938	1.0	0.5340			
5221,	0.4269	0.5596	1.0	0.4136			
5222,	0.1122	0.3617	1.0	0.4595			
6001,	3.8974-2	1.2720-2	2.0799-1	3.1739-2	1.8867-1	1.1602-1	
6002,	4.0941-1	3.1103-1	1.2879-1	1.3999	2.6178-2	3.8689	
9000,	3						
9001,	0.0	0.0	1.50	0.50	1.50	100.0	
10000,	2						
10001,	3.2158+3	0.0	3.2158+3	100.0			
11000,	2						
11001,	0.0	98.0	0.0	1000.0			
12000,	2						
12001,	0.0	0.0	0.0	0.0			
14000,	3						
14001,	0.005	0.0	0.001	0.55	0.005	0.75	
16000,	4						
16001,	0.10	5	0.0	0.05	2	0.50	
16002,	0.05	1	0.60	0.10	5	0.70	
17000,	2						
17001,	1.0	0.0	1.0	20.0			
18000,	2						
18001,	0.0	0.0	-10.0	0.60			

### ATTACHMENT 3

#### Sample Problem Results:

Overpower (12.0 MW) Trip Time = 0.609s

Time to Peak Power = 0.655s

Peak Power = 129.0 MW

Energy to Time of Peak Power = 3.09 MWs

Peak Clad Temperature = 155.4 °C (0.672s)

Peak Coolant Temperature = 84.0 °C (0.744s)